

FEB. 16, 2004 4:18PM HARRIS GCSD

NO. 986 P. 1



IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of:)
GOLDSTEIN)
Serial No. 10/060,497) Examiner: H. Le
Filing Date: JANUARY 30, 2002) Art Unit: 2821
For: PHASED ARRAY ANTENNA INCLUDING)
ARCHIMEDEAN SPIRAL ELEMENT)
ARRAY AND RELATED METHODS)

RECEIVED

DECLARATION UNDER 37 CFR 1.131

FEB 26 2004

MS Non-Fee Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

I, M. Lawrence Goldstein, hereby declare that:

1. I am the sole inventor for the above-identified patent application.

2. Prior to July 11, 2001, I conceived and reduced to practice the invention as described and claimed in the subject patent application, as evidenced by the following documents:

(a) a printout of a MathCAD analysis for an Archimedean spiral lattice that I personally prepared prior to July 11, 2001, which is attached hereto as Appendix A (note the definition of the Archimedean spiral lattice on page 1, and graph

FEB.16.2004 4:18PM HARRIS GCSD

NO.986 P.2

In re Patent Application of:
GOLDSTEIN
Serial No. 10/060,497
Filing Date: JANUARY 30, 2002

and simulation results thereof provided on page 4); and

(b) a printout of a power point presentation also personally prepared by myself prior to July 11, 2001, which is attached hereto as Appendix B, demonstrating MathCAD simulation results for various test configurations of my Archimedean spiral lattice (see pages 1-3 and 9), and also providing Mathcad simulation results for various prior art arrays (namely an aperiodic concentric ring lattice on page 4, and various periodic triangular lattices on pages 5-8) for comparison purposes.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

2/16/03

M. Lawrence Goldstein

The Element

$$\text{cosgain}(\theta, n) := 10 \cdot \log \left[\frac{2 \cdot (|\cos(\theta)|)^n}{\int_0^{\pi/0.5} (|\cos(\theta)|)^n \cdot \sin(\theta) d\theta} \right]$$

cos^n pattern

$$\text{ElementGain}(\theta) := \text{cosgain}(\theta, 2.155) \quad \text{ElementGain}(0 \cdot \text{deg}) = 8$$

$$c := 2.997925 \cdot 10^8 \frac{\text{m}}{\text{sec}} \quad \lambda := \frac{c}{f} \quad k_0 := 2 \cdot \frac{\pi}{\lambda}$$

$$G_{\text{array}} := 10 \cdot \log(N) + \text{ElementGain}(0 \cdot \text{deg})$$

The Array

$$\text{Next}(\theta_1) := \begin{cases} \Delta\theta \leftarrow 10 \cdot \text{deg} \\ \theta_2 \leftarrow \theta_1 + \Delta\theta \\ \text{for } i \in 1..5 \\ \quad \theta_2 \leftarrow \theta_2 - \Delta\theta \\ \quad \Delta\theta \leftarrow \frac{\Delta\theta}{10} \\ \text{while } 4\pi^2 \geq \theta_1^2 + \theta_2^2 - 2 \cdot \theta_1 \cdot \theta_2 \cdot \cos(\theta_1 - \theta_2) \\ \quad \theta_2 \leftarrow \theta_2 + \Delta\theta \\ \theta_2 \end{cases}$$

The Subarray

$$s := 10 \frac{\text{ElementGain}(0 \cdot \text{deg})}{20} \frac{\lambda}{\pi} \quad s = 1.123 \text{ in}$$

required min spacing

$$\theta_{s_1} := 0 \cdot \text{deg} \quad i := 2..N \quad \theta_{s_i} := \text{Next}(\theta_{s_{i-1}}) \quad i := 1..N \quad d_{i,1} := \theta_{s_i} \cdot \cos(\theta_{s_i}) \cdot \frac{s}{2\pi} \quad d_{i,2} := \theta_{s_i} \cdot \sin(\theta_{s_i}) \cdot \frac{s}{2\pi} \quad \text{array lattice}$$

$$k := 1..N \quad \Delta d_{i,k} := \text{if } i = k, 1000 \cdot \text{in}, \sqrt{(d_{i,1} - d_{k,1})^2 + (d_{i,2} - d_{k,2})^2} \text{ min}(\Delta d) = 1.119 \text{ in} \quad \text{min spacing}$$

$$D := \text{max} \left(\sqrt{(d_{1,1})^2 + (d_{1,2})^2}, 2 + s \right) \quad \eta := N \cdot \left(\frac{s}{D} \right)^2 \quad \text{aperture efficiency}$$

beamforming

$PQ(\alpha) := \text{round}\left(\frac{\alpha \cdot 2^{\text{nbits}}}{2 \cdot \pi}\right) \cdot \frac{2 \cdot \pi}{2^{\text{nbits}}}$ phase quantization for an n -bit phase shifter

$\text{Err}(x) := x \cdot \left[10^{\frac{\text{rnd}(\text{MagErr}) - 0.5 \cdot \text{MagErr}}{20}} \cdot j \cdot (\text{rnd}(\text{PhaseErr}) - 0.5 \cdot \text{PhaseErr}) \cdot \text{deg} \right]$ random mag & phase errors

$w_i := \text{Err}_e \left[j \cdot PQ \left[k_o \cdot \sin(\theta_o) \cdot \left[(d^{(i)})_i \cdot \cos(\phi_o) + (d^{(2)})_i \cdot \sin(\phi_o) \right] \right] \right]$ array element weights

$AG(\theta, \phi) := 10 \cdot \log \left[\frac{\left[\left[\sum_i w_i e^{-j \cdot k_o \cdot \sin(\theta)} \cdot \left[(d^{(i)})_i \cdot \cos(\phi) + (d^{(2)})_i \cdot \sin(\phi) \right] \right]^2 \right]^2}{Pt} + \text{ElementGain}(\theta) \right]$ array gain

$\Delta\theta := 1 \cdot \text{deg}$ $N\theta := \frac{90 \cdot \text{deg}}{\Delta\theta} + 1$ $\theta_i := 1 \dots N\theta$ $\theta_{\theta_i} := (\theta_i - 1) \cdot \Delta\theta$ elevation cut points

$\Delta\phi := 3 \cdot \text{deg}$ $N\phi := \frac{360 \cdot \text{deg}}{\Delta\phi}$ $\phi_i := 1 \dots N\phi$ $\phi_{\phi_i} := (\phi_i - 1) \cdot \Delta\phi$ azimuth cut points

$MBG := AG(\theta_o, \phi_o)$

```
BW(cut, Δψ) := 
$$\begin{cases} pt \leftarrow \text{max}(\text{cut}) \\ \text{for } i \in 1 \dots \text{rows}(\text{cut}) \\ \quad \text{indx} \leftarrow i \text{ if } \text{cut}_i = pt \\ \quad i1 \leftarrow \text{indx} \\ \quad \text{while } \text{cut}_{i1+1} \leq \text{cut}_{i1} \vee \text{cut}_{i1+2} \leq \text{cut}_{i1} \vee \text{cut}_{i1+3} \leq \text{cut}_{i1} \\ \quad \quad i1 \leftarrow i1 + 1 \\ \quad \text{if } i1 > \text{rows}(\text{cut}) \\ \quad \quad \quad i2 \leftarrow \text{indx} \\ \quad \quad \text{while } \text{cut}_{i2-1} \leq \text{cut}_{i2} \vee \text{cut}_{i2-2} \leq \text{cut}_{i2} \vee \text{cut}_{i2-3} \leq \text{cut}_{i2} \\ \quad \quad \quad \quad i2 \leftarrow i2 - 1 \\ \quad \quad \quad \quad (i1 - i2) \cdot \Delta\psi \end{cases}$$

```

```

HPBW(cut,Δψ) := | pt ← max(cut)
                   | for i ∈ 1..rows(cut)
                   |   idx ← i if cuti = pt
                   |   i1 ← idx
                   |   while cuti1+1 > pt - 3
                   |     i1 ← i1 + 1
                   |   i2 ← idx
                   |   while cuti2-1 > pt - 3
                   |     i2 ← i2 - 1
                   |   (i1 - i2 + 1)·Δψ
                   |
                   | φcutφi := AG(θo,φφi) - MBG   BWφ := BW(φcut,Δφ)   BWφ = 36 deg
                   | θcutθi := AG(θθi,φo) - MBG   BWθ := BW(θcut,Δθ)   BWθ = 20 deg
                   | HPBWθ := HPBW(θcut,Δθ)   HPBWφ := HPBW(φcut,Δφ)
                   |
                   | Hemiφi,θi := AG(θθi,φφi) - MBG   Hemiφi,θi := if (Hemiφi,θi < SLLgoal - 0.5, SLLgoal - 0.5, Hemiφi,θi)|| hemispherical pattern normalized & clipped
                   | SLLcompliance := | cnt ← 0
                           |   for i ∈ 1..Nθ
                           |     for k ∈ 1..Nθ
                           |       cnt ← cnt + 1 if (Hemik,i ≤ SLLgoal) ∨ (|φo - φk| ≤ BWφ ∧ |θo - θk| ≤ BWθ) ⊥L compliance
                           |       cnt
                           |   Nφ·Nθ

```

DESIGN

ElementGain(0·deg) = 8 $f = 8.4\text{-GHz}$ element pattern file & frequency
SLL_{goal} ≡ -12.5 peak sidelobe compliance level

$\theta_0 \equiv 30\text{-deg}$ $\phi_0 \equiv 90\text{-deg}$ selected beam steering angles

nbits ≡ 4 # of phase shifter bits

MagErr ≡ 1.7 PhaseErr ≡ 30·deg random magnitude error (dB) & random phase errors
N ≡ 72 # of elements (1,8,21,40,64) required min spacing

$G_{\text{array}} = 26.6$

SLL.compliance = 99.9 %

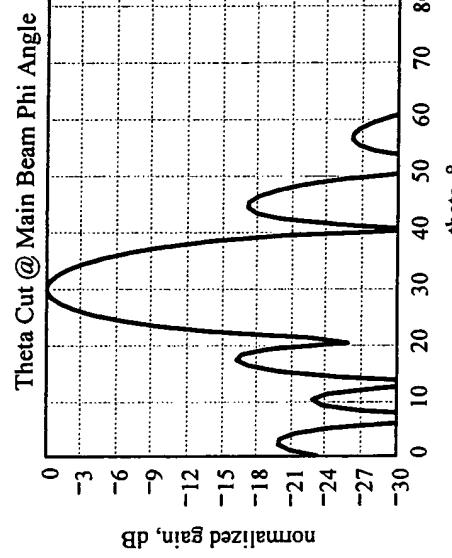
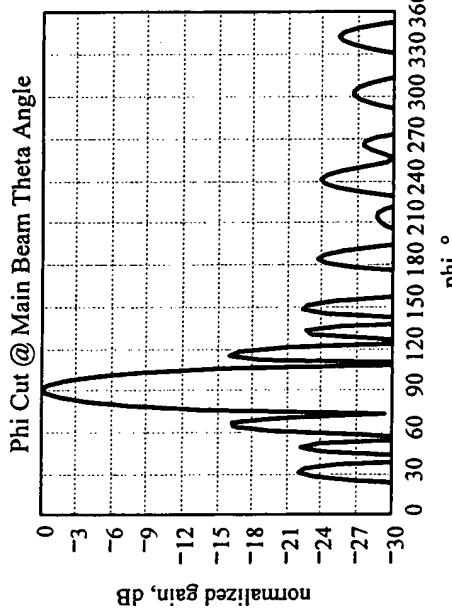
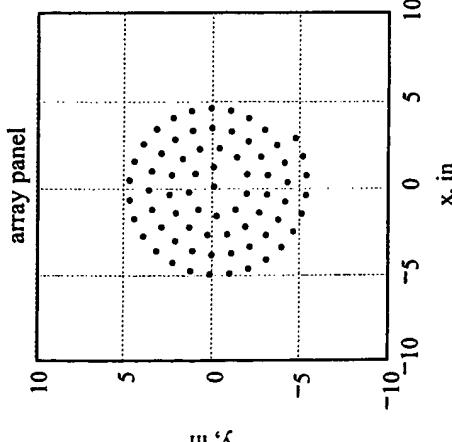
MBG = 25.2

HPBW_φ = 15 deg

HPBW_θ = 8 deg

D = 1 ft D = 12 in array efficiency & diameter

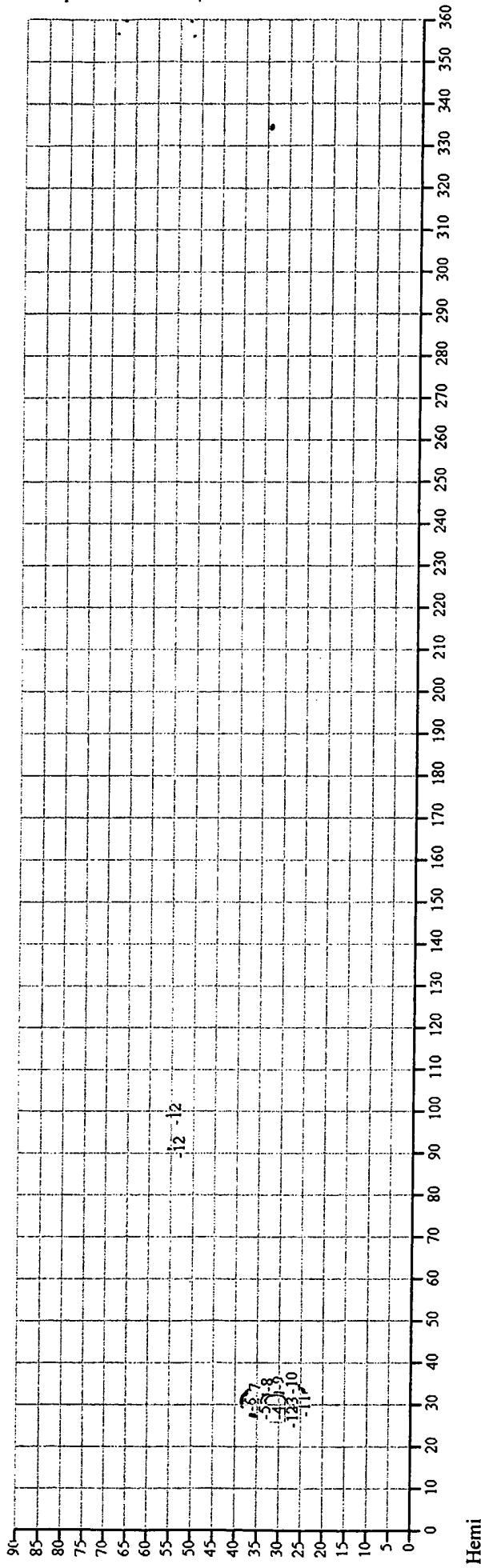
$s = 1.123\text{ in}$



maximum possible array gain (dB_{iC})

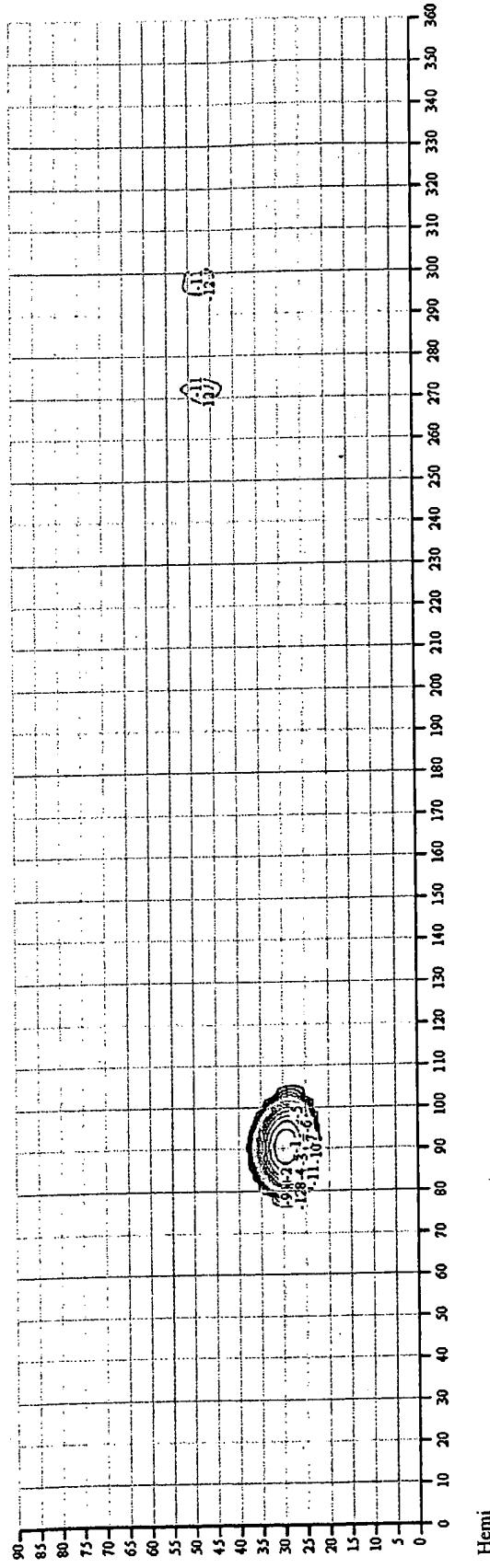
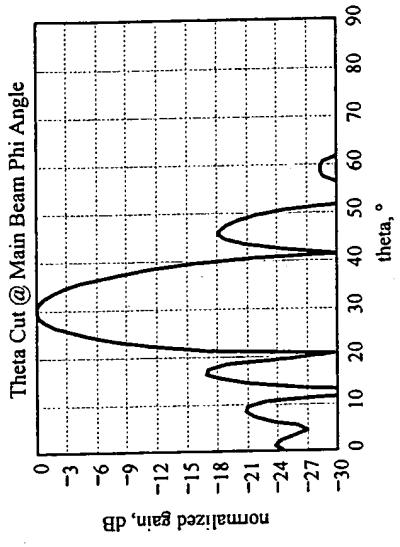
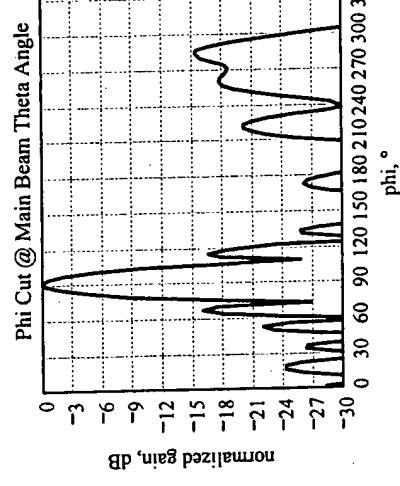
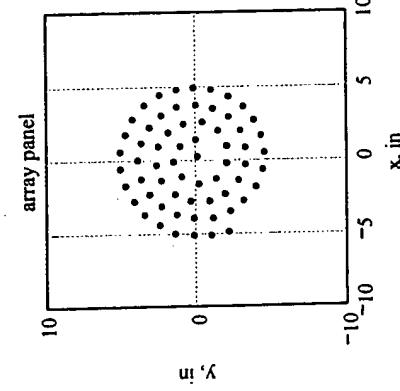
SLL compliance

scanned main beam gain (dB_{iC})



Not on chart

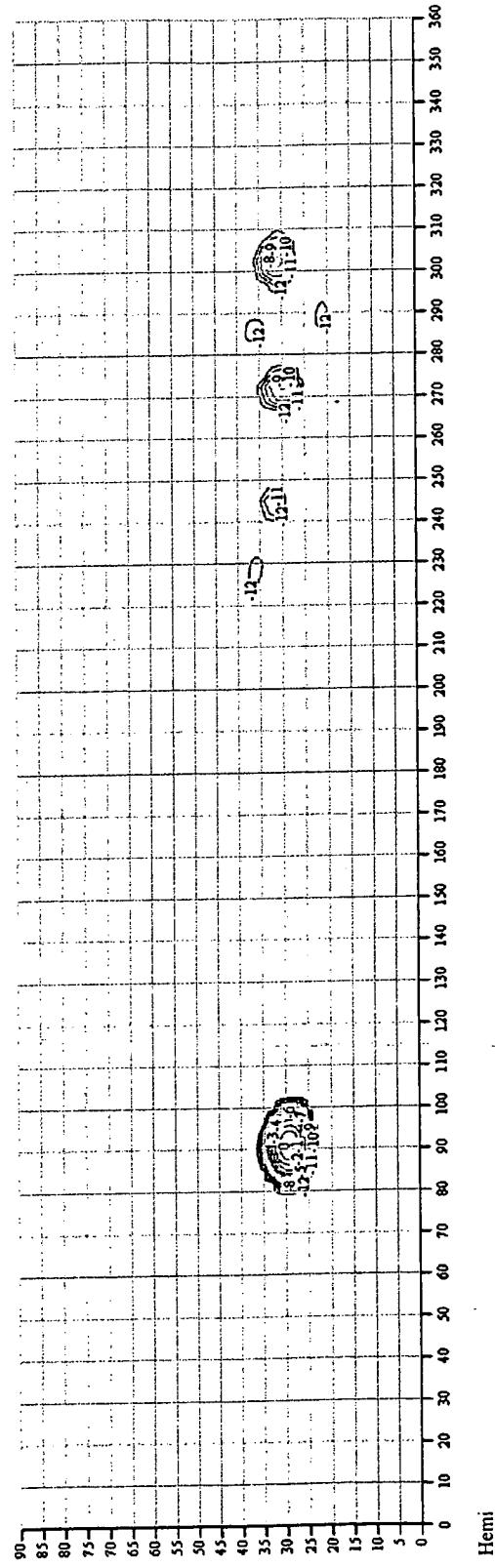
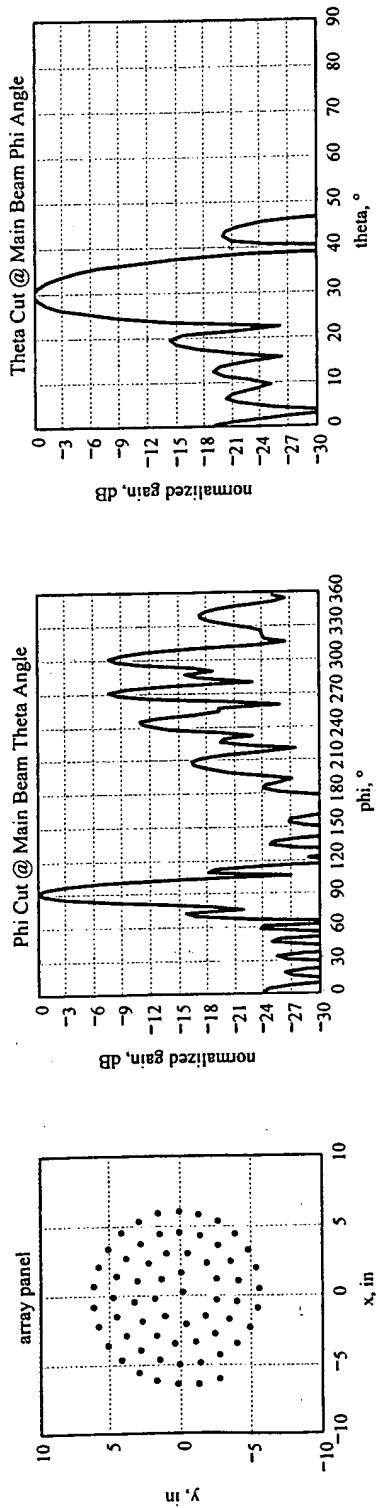
Efficiency	$f = 8.4 \text{ GHz}$	element gain & frequency
SLLgoal $\equiv -12.5$		peak sidelobe compliance level
$\theta_0 \equiv 30\text{-deg}$	$\phi_0 \equiv 90\text{-deg}$	selected beam steering angles
nbits $\equiv 4$		# of phase shifter bits
MagErr $\equiv 1.7$	PhaseErr $\equiv 30\text{-deg}$	random magnitude error (dB) & random phase errors
N = 64		# of elements (1,8,21,40,64)
		bore sight HPBW
		$\lambda \cdot D^{-1} = 6.68\text{deg}$



Hemi

Not on chart

SLI goal	≈ -12.5	$f = 8.4 \text{ GHz}$	element gain & frequency peak sidelobe compliance level	$G_{\text{array}} = 28.4$	maximum possible array gain (dBIC)
$\theta_0 = 30\text{-deg}$	$\phi_0 = 90\text{-deg}$		selected beam, steering angles # of phase shifter bits	$\text{MBG} = 25.6$	SLL compliance
$n_{\text{bits}} = 4$		$\text{PhaseErr} \equiv 30\text{-deg}$	random magnitude error (dB) & random phase errors # of elements /11,8,21,40,64/	$\text{HPBW}_{\phi} = 12\text{deg}$	scanned main beam gain (dBIC)
$\text{MagErr} \equiv 1.7$				$\text{HPBW}_{\theta} = 8\text{deg}$	HPBWs
				$\eta = 62.398\%$	array efficiency & diameter D = 1.2 ft
					s = 1.471 in
					boresight HPBW



Row6 @ 8.4 GHz



$f = 8.4 \text{ GHz}$ element gain & frequency

lattice filename

lattice \equiv "archimed.txt"

SLLgoal $\equiv -12.5$

$\theta_0 \equiv 90 \text{ deg}$ $\phi_0 \equiv 90 \text{ deg}$

$n_{\text{bits}} \equiv 4$

MagErr $\equiv 1.7$ PhaseErr $\equiv 30 \text{ deg}$

$$\lambda \cdot D^{-1} \cdot 1.02 = 5.499 \text{ deg}$$

Garray = 28.4

maximum possible array gain (dBiC)

SLL compliance & peak SLL (dB)

scanned main beam gain (dBiC)

main beam HPBWs

array efficiency & diameter

required minimum element spacing

of phase shifter bits

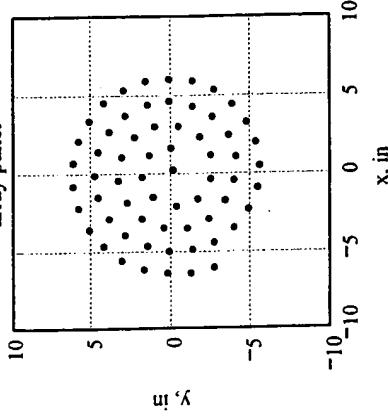
uniform random magnitude (dB) & phase errors

of elements

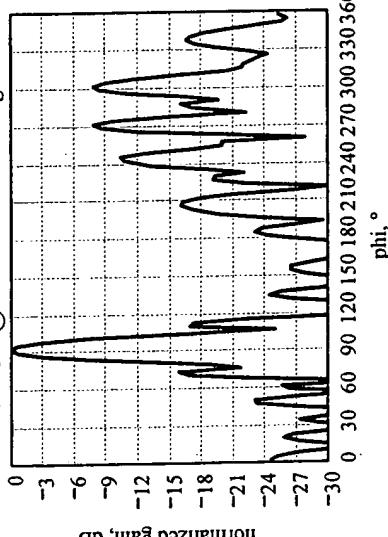
$\eta = 62\%$ $D = 1.2 \text{ ft}$

$s = 1.47 \text{ in}$

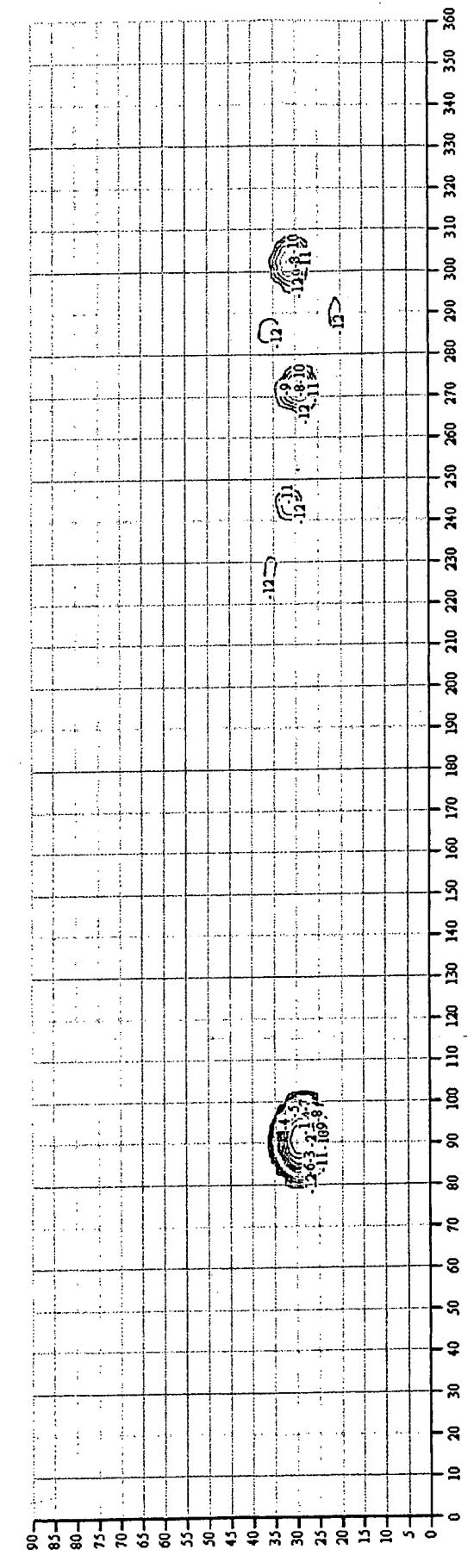
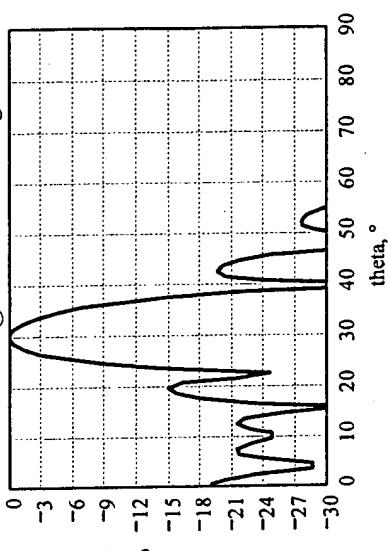
array panel



Phi Cut @ Main Beam Theta Angle



Theta Cut @ Main Beam Phi Angle

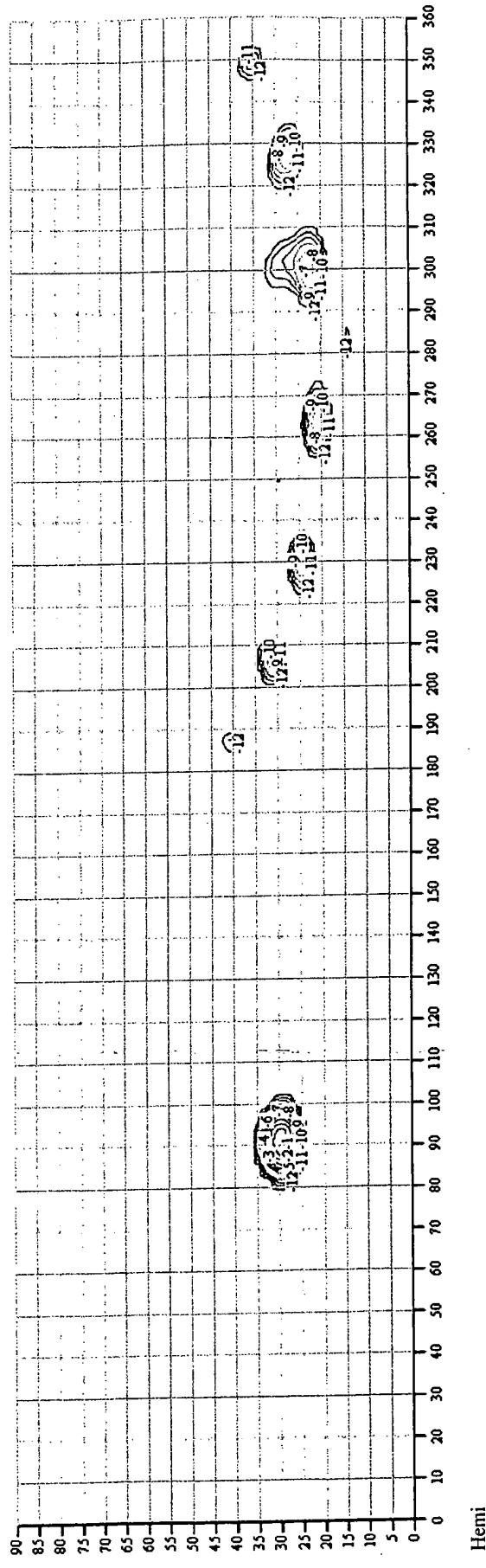
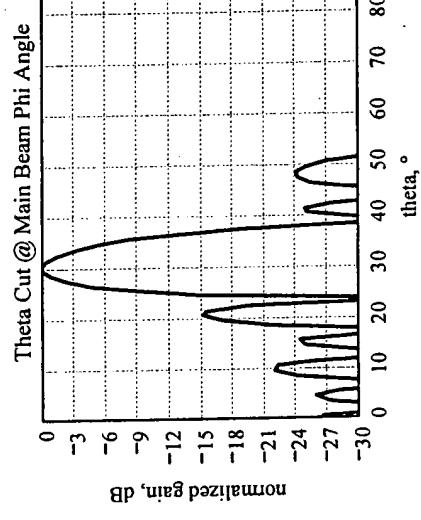
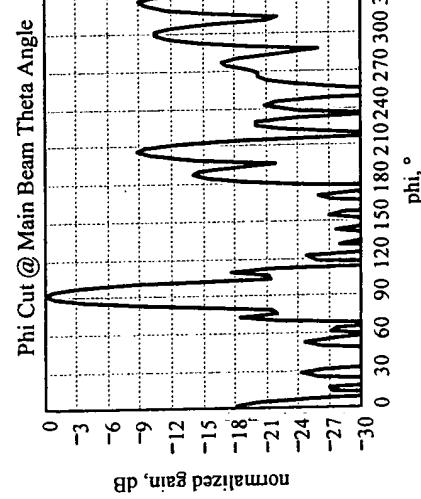
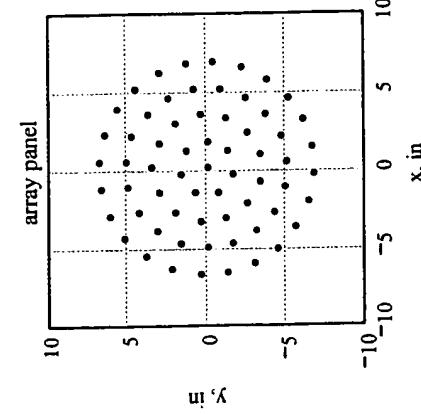


Hemi

Row7 @ 8.4 GHz

Element Gain

$f \equiv 8.4 \text{ GHz}$	element gain & frequency	$\lambda \cdot D^{-1} \cdot 1.02 = 5.427 \text{ deg}$	boresight HPBW
lattice = "juniper.txt"	lattice filename	$G_{\text{array}} = 28.4$	maximum possible array gain (dBic)
SLLgoal = -12.5	peak sidelobe compliance level	$SLL_{\text{compliance}} = -9.87 \text{ dB}$	SLL compliance & peak SLL (dB)
$\theta_0 = 30 \text{ deg}$	selected beam steering angles	$MBG = 25.6$	scanned main beam gain (dBic)
nbits = 4	# of phase shifter bits	$HPBW_{\phi} = 9 \text{ deg}$	main beam HPBWs
MagErr = 1.7	uniform random magnitude (dB) & phase errors	$HPBW_{\theta} = 7 \text{ deg}$	array efficiency & diameter
	# of elements	$s = 1.47 \text{ in}$	required minimum element spacing



Hemi

Row2 @ 8.4 GHz

Element Cut @ 8.4 GHz

lattice \equiv "trip6.txt"

SLLgoal \equiv -12.5

$\phi_0 \equiv 30$ -deg

nbits \equiv 4

MagErr \equiv 1.7

PhaseErr \equiv 30-deg

trip6

$f \equiv 8.4$ GHz

element gain & frequency

lattice filername

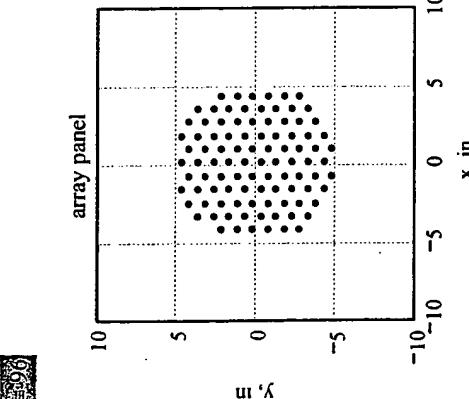
peak sidelobe compliance level

selected beam steering angles

of phase shifter bits

uniform random magnitude (dB) & phase errors

of elements



$\lambda \cdot D^{-1} \cdot 1.02 = 7.4$ deg

Garray = 26.7

SLL compliance & peak SLL (dB)

MBG = 25.75

HPBW ϕ = 15 deg

HPBW θ = 9 deg

D = 11.79 in

s = 0.99 in

bore sight HPBW

maximum possible array gain (dB/C)

SLL compliance & peak SLL (dB).

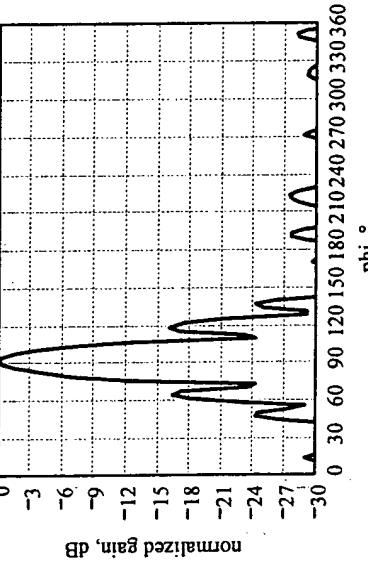
scanned main beam gain (dB/C)

main beam HPBWs

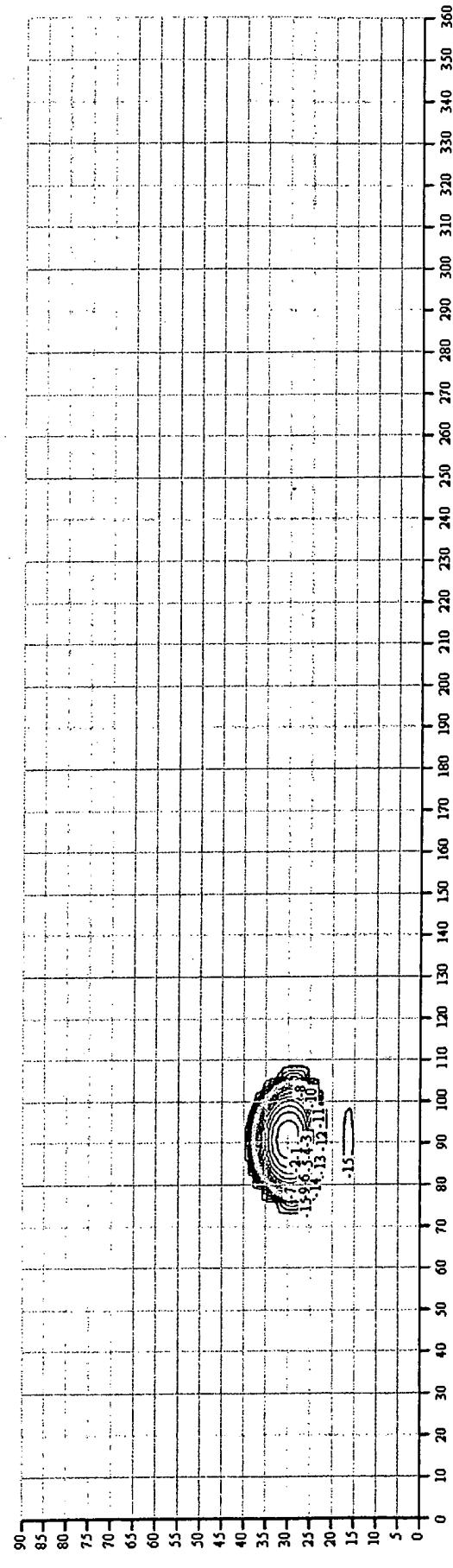
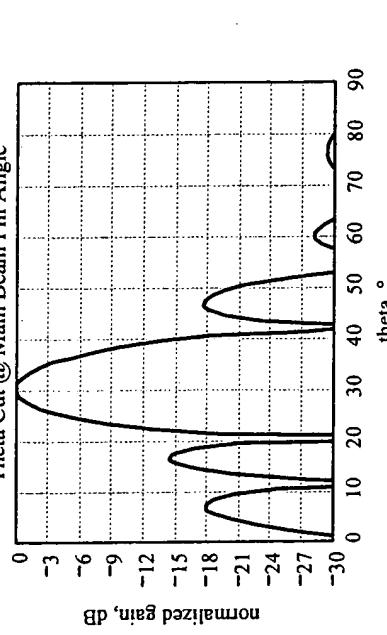
array efficiency & diameter

required minimum element spacing

Phi Cut @ Main Beam Theta Angle



Theta Cut @ Main Beam Phi Angle



5

NOT ON CHART

Element filename: "tri96.txt"
 lattice = "tri96.txt"
 SLI goal = -12.5
 $\theta_0 = 30\text{-deg}$ $\phi_0 = 90\text{-deg}$
 nbits = 4
 MagErr = 1.7


element gain & frequency

$$\lambda \cdot D^{-1}, 1.02 = 7\text{ deg}$$

lattice filename

maximum possible array gain (dBjC)

peak sidelobe compliance level

SLL compliance & peak SLL (dB)

selected beam steering angles

scanned main beam gain (dBjC)

of phase shifter bits

main beam HPBW_s

uniform random magnitude (dB) & phase errors

array efficiency & diameter

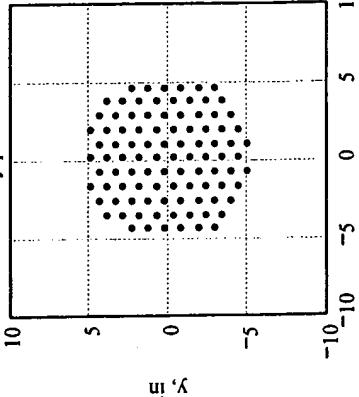
of elements

required minimum element spacing

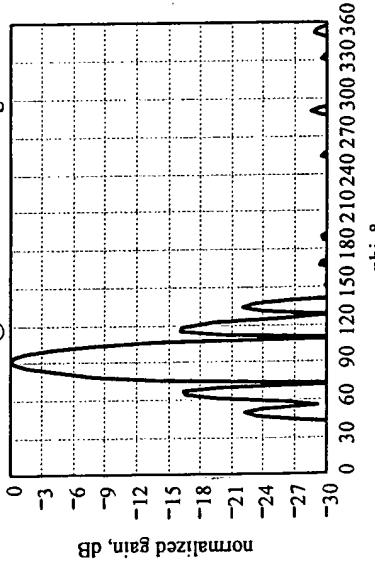
$$s = 1.039\text{ in}$$

$$\text{PhaseErr} \equiv 30\text{-deg}$$

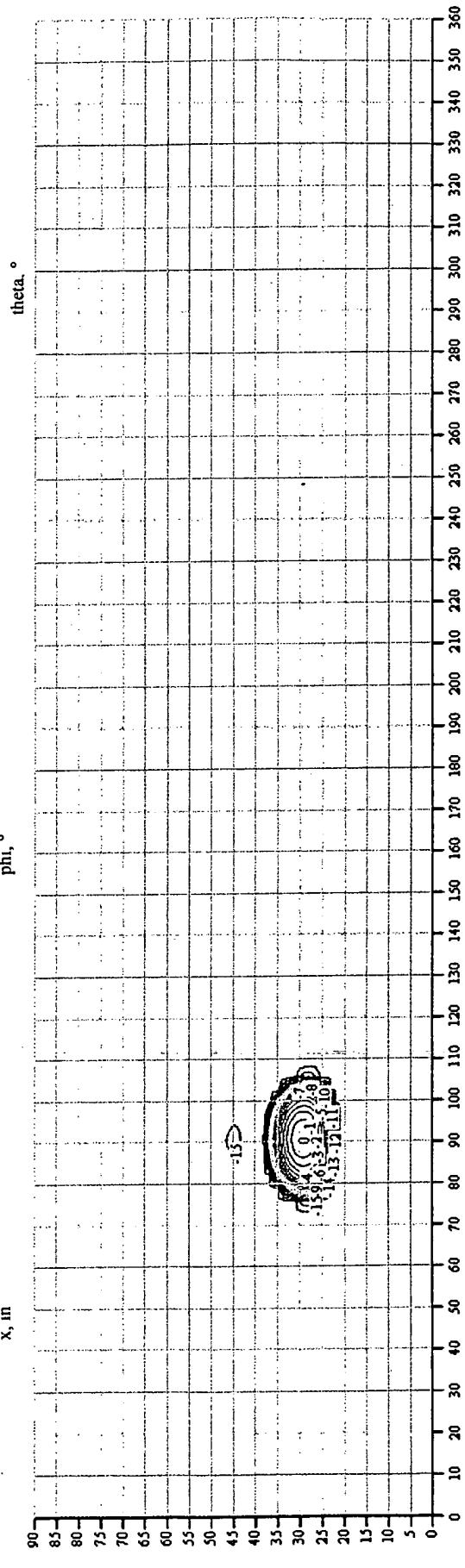
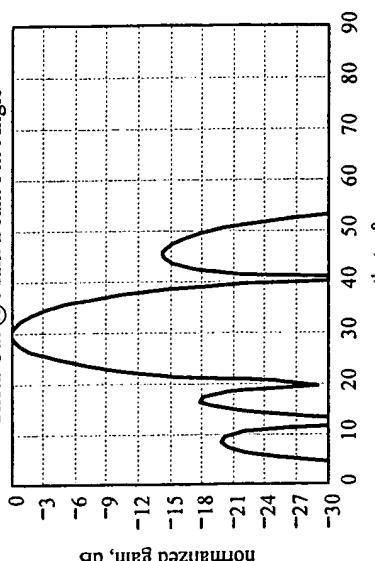
array panel



Phi Cut @ Main Beam Theta Angle

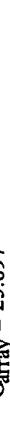


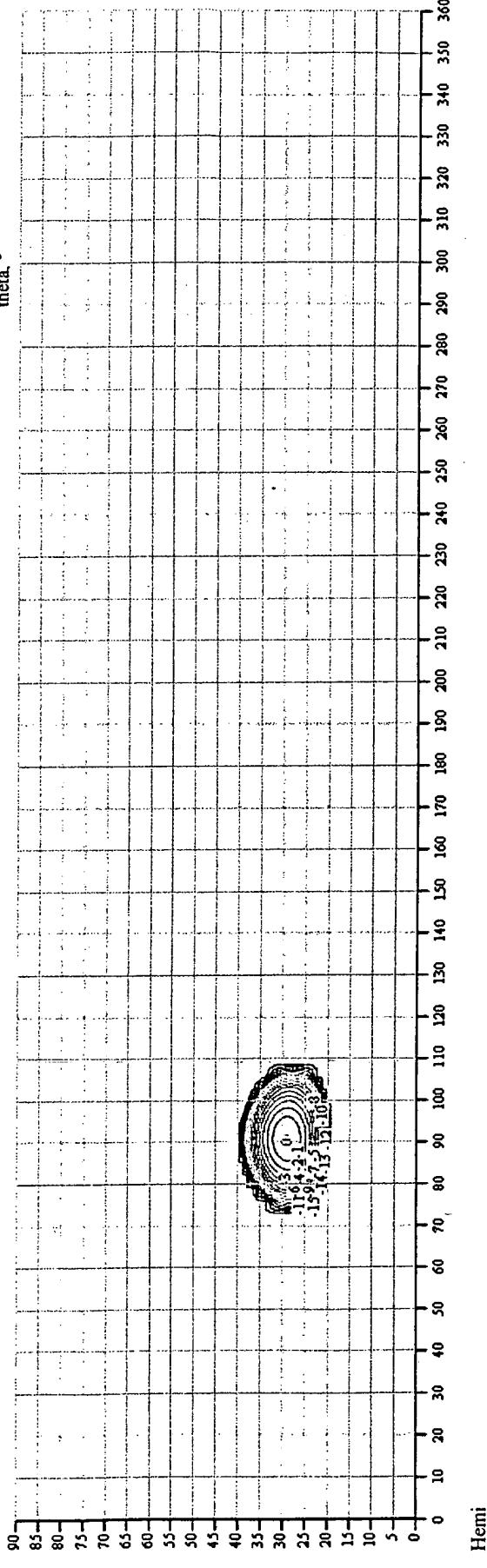
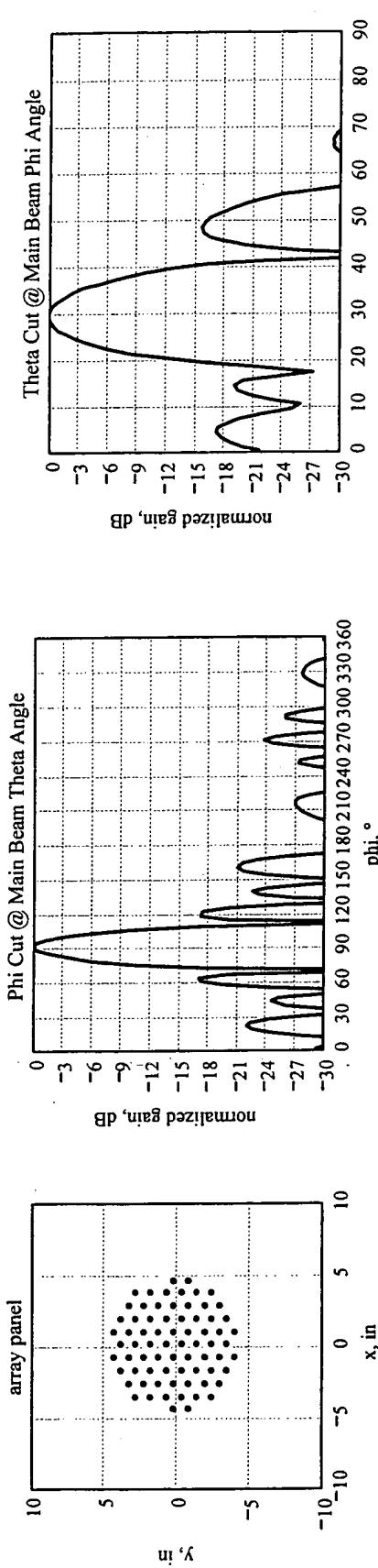
Theta Cut @ Main Beam Phi Angle



Hemi

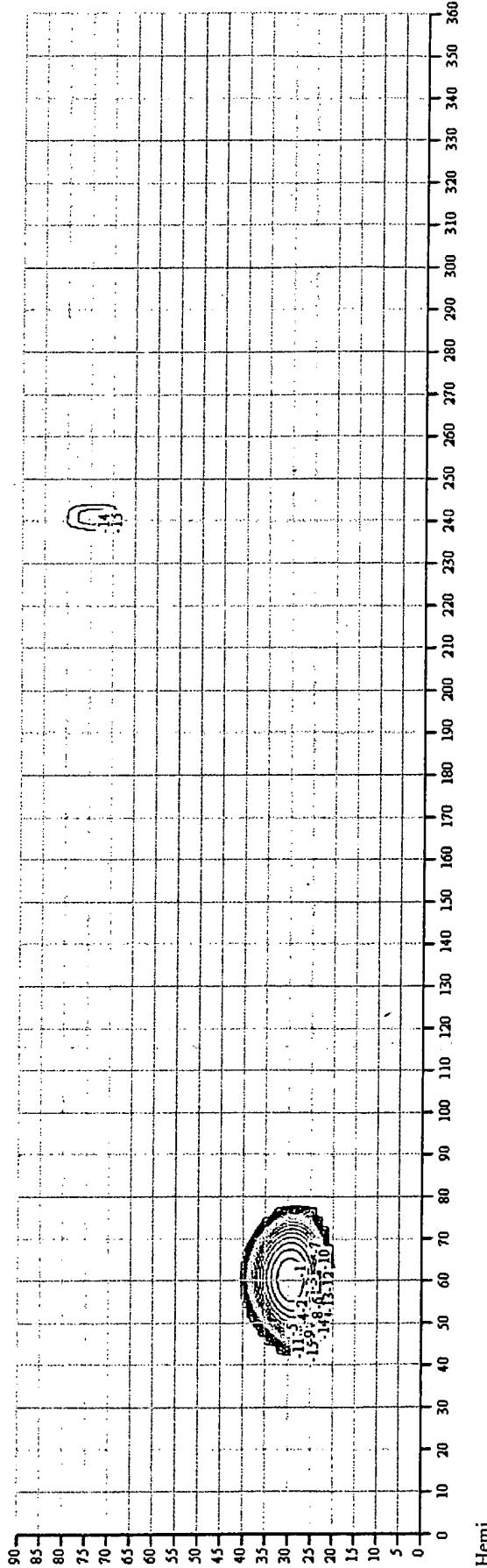
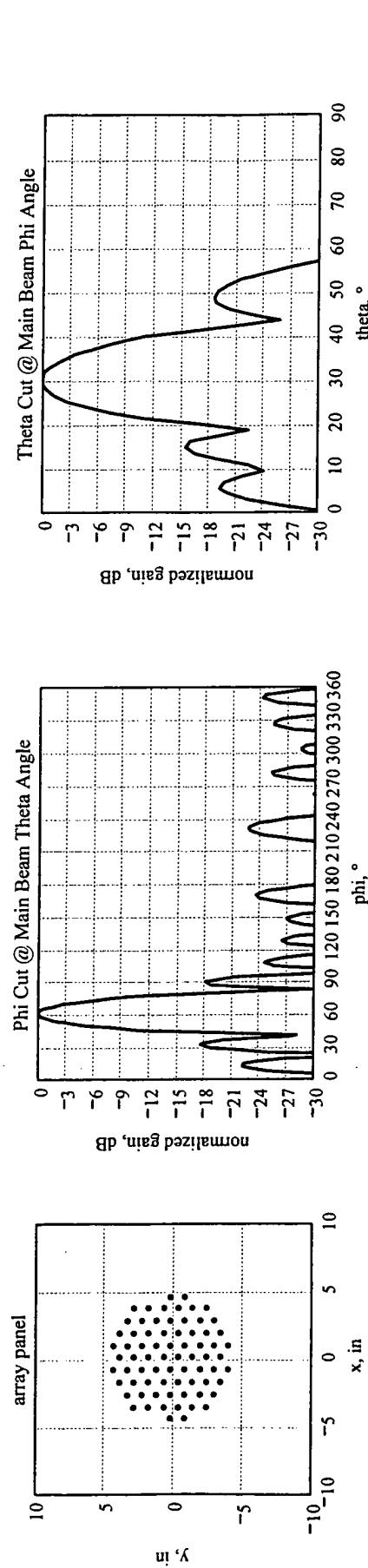
Row5 @ 8.4 GHz

$f = 8.4 \text{ GHz}$	element gain & frequency	$\lambda \cdot D^{-1} \cdot 1.02 = 8.01 \text{ deg}$	boresight HPBW
$\text{lattice} = \text{"lat72.txt"}$	lattice filename	$G_{\text{array}} = 25.897$	maximum possible array gain (dBic)
$\text{SLLgoal} = -12.5$	peak sidelobe compliance level		SLL compliance & peak SLL (dB)
$\theta_0 = 30 \text{ deg}$	selected beam steering angles		scanned main beam gain (dBic)
$n_{\text{bits}} = 4$	# of phase shifter bits		main beam HPBWs
$\text{MagE}\pi \equiv 1.7$	uniform random magnitude (dB) & phase errors		array efficiency & diameter
$\text{PhaseE}\pi \equiv 30 \text{ deg}$	# of elements		required minimum element spacing



72 element triangular lattice scaled 1.05 - scanned to phi=60° (worst case not phi=90°)

lattice \equiv "lat12.txt"	element gain & frequency $f = 8.4 \text{ GHz}$	lattice filename	$\lambda \cdot D^{-1} \cdot 1.02 = 8.01 \text{ deg}$	theoretical boresight HPBW
SLLgoal \equiv -12.5	peak sidelobe compliance level			maximum possible array gain (dBIC)
$\theta_0 \equiv 30\text{-deg}$	selected beam steering angles			SLL compliance & peak SLL (dB)
nbits \equiv 4	# of phase shifter bits			scanned main beam gain (dBIC)
MagEpi \equiv 1.7	PhaseErr \equiv 30-deg			main beam HPBWs
	# of elements			array efficiency & diameter
				required minimum element spacing



8

Hemi

64 element archimedean spiral lattice with 7.78 dB elements - scanned to $\phi = 60^\circ$ (worst case?)

Case 3 (Worst Case)	
$f = 8.4 \text{ GHz}$	element gain & frequency
$\text{lattice} \equiv \text{"regspiral.txt"}$	lattice filename
$\text{SLLgoal} \equiv -12.5$	peak sidelobe compliance level
$\theta_0 \equiv 30\text{-deg}$	selected beam steering angles
$n\text{bits} \equiv 4$	# of phase shifter bits
$\text{MagErr} \equiv 1.7$	uniform random magnitude (dB) & phase errors
$\text{PhaseErr} \equiv 30\text{-deg}$	# of elements
	MBG = 24.536
	$\text{HPBW}_\phi = 16\text{deg}$
	$\text{HPBW}_\theta = 9.7\text{deg}$
	$\eta = 62.013\%$
	$D = 0.9 \text{ ft}$
	$\text{SLL} = -1.02 = 7.37\text{deg}$
	$\text{Garray} = 25.843$
	$\text{SLL compliance \& peak SLL (dB)}$
	scanned main beam gain (dBIC)
	main beam HPBWs
	theoretical bore sight HPBW
	maximum possible array gain (dBIC)
	array efficiency & diameter
	required minimum element spacing

